Observations on the behaviour of clams in waters of low salinity

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(*With seven text-figures*)

Of the several species of venerid clams that occur on the coast of Maharashtra State, *Meretrix meretrix* L. and *Katelysia opima* Gml. contribute nearly 70 per cent of the total catch of clams landed annually. They are found in most of the estuaries and backwaters of the coastal belt of the state. The clams being found mostly in the estuarine environment, are naturally subjected to fluctuating ecological conditions which exert great influence on their life. During ebb tide, specially during spring low tide, the clam beds get exposed to air, resulting in desiccation of animals. There are great fluctuations in salinity owing to tidal oscillations and river discharge. During monsoon, the salinity of the water over the clam beds may remain low for a long period. The clams in such areas, therefore, have to adapt themselves to overcome these changes. Survival and behaviour of clams in low salinities have been studied by many workers in case of the temperate species. Most of these studies have been made on the edible oysters by Amemiya (1928), Hopkins (1936), Ingle & Dawson (1950) and Loosanoff (1948, 1950, 1952), Chalney (1958) has studied survival of juvenile bivalves in waters of low salinities and Motwani (1956) studied adaptations in *Mytilus edulis* to salinity fluctuations. No work appears to have been done on the survival and behaviour of bivalves from Indian waters, in waters of low salinity, though this aspect is considered important from the management point of view, especially if culture operations are to be undertaken. The present investigation was, therefore, undertaken to study the survival and behaviour of clams, *Meretrix meretrix* and *Katelysia opima* in waters of low salinities.

While studying the biology of these clams, it was found that the salinity of the water in the Kalbadevi estuary, from where the clams were collected, varied from 4‰ to 35.8‰ during the year. The lowest salinity was observed in the months of July and August on account of rain and flooding of the river. However, no large scale mortality of clams was observed. It was, therefore, natural to assume that these clams could tolerate wide fluctuations in the salinity. Some of the clams brought from the beds, when the salinity was high (34·0‰), on transfer to pure fresh water, were found to close their valves immediately, remaining in this condition for even two days ; but when re-transferred to sea water, they opened their valves within a short time. The closure of the shell valves becomes an adaptation to withstand unfavourable conditions in the environment, thereby keeping the mantle fluid unaffected by external changes. This adaptation is only a temporary measure, so long the animal is able to live without opening the valves for both respiration and feeding. Besides, it has also been observed that the salinity has great influence on the growth and breeding of these clams.

The purpose of the present work was, therefore, to investigate how far these clams are adapted to the environment so far as the changes in the salinity were concerned. This was done by conducting a series of experiments in the laboratory to determine the following objectives :

(1) The low salinity tolerance range.

(2) Time taken in opening of the valves in relation to salinity.

(3) Efficiency of the valve-closing mechanism.

(4) The nature of stimulus which controls opening and closing of valves.

Material and methods

Live specimens of both species were brought from the Kalbadevi estuary, washed and kept in sea water in large trays in the laboratory. The sea water in these trays was changed every day. A period of 48 hours was found to be sufficient for the clams to be conditioned and for throwing adequate extraneous matter. From November to March the period during which these experiments were conducted, the salinity of the sea water over the clam bed varies between 30‰ and 34‰, whereas that of the sea water brought to the laboratory varied between 33‰ and 35‰. Various dilutions of sea water in the laboratory were made by adding distilled water. No food was given to the clams while under storage and experimental conditions. During ten days' observations of the salinity tolerance experiments, sea water of requisite concentration was replaced every 48 hours. Salinity of the sea water was determined by titration with silver nitrate, using potassium chromate as an indicator.

Results

(1) *Low salinity-tolerance range*

Experiments were conducted in enamel trays, each of which was filled with two litres of sea water of varying dilutions as required. In all the experiments, only one size range of clams was selected ; for *M. meretrix* 35 mm to 40 mm and for *K. opima* and 25 mm to 30 mm as these sizes were common in the commercial catches landed at Ratnagiri. Water in which the clams were subjected for tolerance studies ranged from fresh water to 100 per cent sea water (salinity 35‰), with intermediate percentage namely 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90. In each tray, 20 clams were subjected for a period of ten days. The dilutions, wherein the survival was 50 per cent and above at the end of this period, were regarded as a ' tolerating ' range. The clam was considered as dead, if it did not close or react when touched with a glass rod.

The results of the experiment on *K. opima* are given in Table I and are shown graphically in Fig. 1.

Table I

Percentage mortality of *K. opima* in various concentrations

No. of days	Percentage of sea water 0%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.	—	—	—	—	—	—	—	—	—	—	—	—
2.	30	25	25	10	5	—	—	—	—	—	—	—
3.	50	40	35	20	5	—	—	—	—	—	—	—
4.	15	15	20	45	20	—	—	—	—	—	—	—
5.	5	20	20	25	50	5	—	—	—	—	—	—
6.	—	—	—	—	20	10	5	—	—	—	—	—
7.	—	—	—	—	—	10	—	—	—	—	—	—
8.	—	—	—	—	—	5	5	5	—	—	—	—
9.	—	—	—	—	—	—	—	—	—	—	—	—
10.	—	—	—	—	—	10	10	5	—	—	—	—
	100%	100%	100%	100%	100%	40%	20%	10%	0%	0%	0%	0%

From the graph, it would be seen that in dilution from 0% to 30% sea water, there was 100% mortality within six days of the commencement of the experiment. In 40% sea water, it was observed that only 15% mortality took place at the end of six days, and 40% at the end of ten days. The curve for 40% sea water considerably deviates from those of the lower grades indicating that the tolerance-range has been approached and that the clams can tolerate this salinity as adjudged by 50% survival at the end of ten days period. In 50% sea water there was only 5% mortality in six days and 20% mortality in ten days. The curve for 50% sea water shows still further deviation. In 60% sea water there was no mortality at the end of six days and only 10% mortality at the end of ten days, whereas in sea water of 70% and above there was no mortality at the end of ten days. From this, it can be inferred that *K. opima* could tolerate low salinity as much as 40% sea water or salinity of 14·0‰ under laboratory conditions when the transfer to low salinities is sudden.

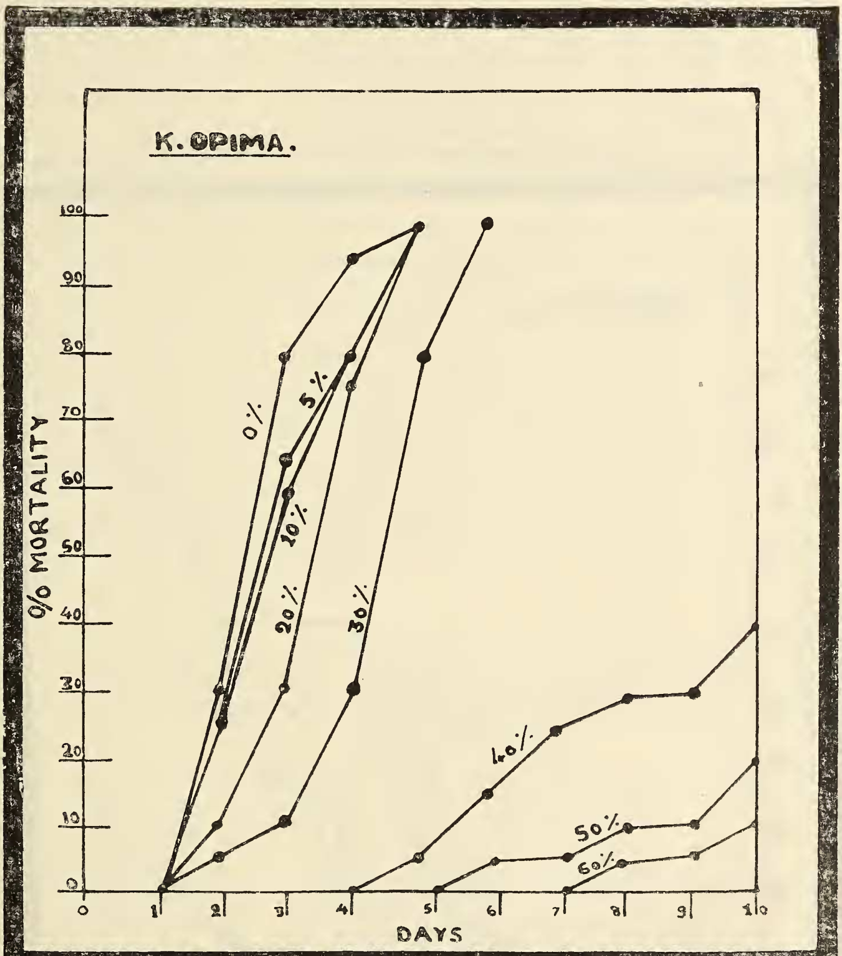

FIG. 1.

The results of the experiments conducted on *M. meretrix* are given in Table II and are shown graphically in Fig. 2.

TABLE II

PERCENTAGE MORTALITY OF *M. meretrix* IN VARIOUS CONCENTRATIONS

No. of days	Percentage of sea water 0%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.	—	—	—	—	—	—	—	—	—	—	—	—
2.	—	—	—	—	—	—	—	—	—	—	—	—
3.	5	—	—	—	—	—	—	—	—	—	—	—
4.	10	10	5	—	—	—	—	—	—	—	—	—
5.	25	15	5	5	—	—	—	—	—	—	—	—
6.	25	30	10	10	10	—	—	—	—	—	—	—
7.	—	—	30	25	5	—	—	—	—	—	—	—
8.	5	10	10	10	—	—	—	—	—	—	—	—
9.	15	25	30	15	5	5	—	—	—	—	—	—
10.	15	10	10	35	10	5	—	—	—	—	—	—
	100%	100%	100%	100%	30%	10%						

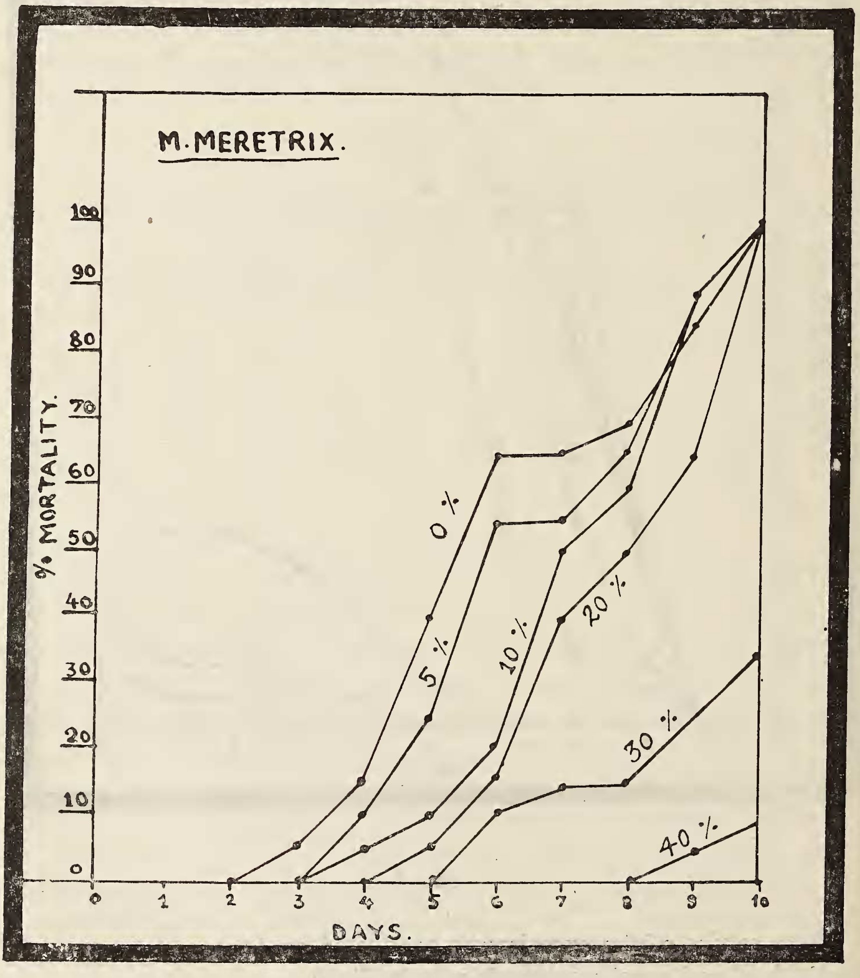

FIG 2.

From the graph, it would be seen that in dilutions from 0-20% sea water, there was 100% mortality in ten days. However, in 30% sea water at the end of ten days the mortality was only 30% indicating that this dilution was better tolerated by clams. The curve for 30% sea water also deviates considerably from the curves of 0% to 20% indicating that 30% is within tolerance range for the species as adjudged by 50% survival at the end of ten days. There is no mortality till eighth day in 40% sea water and the total mortality in ten days was only 10%. In percentages higher than 40% sea water there was no mortality at the end of ten days.

From this it can be concluded that *M. meretrix* is more tolerant to low salinities than *K. opima* and that it can withstand low salinity as much as 30% sea water (salinity 10.5‰) under laboratory conditions when the change to low salinities is effected suddenly.

The experiments on salinity-tolerance studies were conducted during the period November to March, when the salinity of the sea water at the clam beds varied only between 30‰ and 34%. It has been observed that this salinity is greatly reduced during the rainy season and at times reaches as low as 1.4‰ or nearly almost fresh-water. The average salinity during July and August varies between 4‰ to 12‰. The lethal limits of 14‰ and 10.5‰ for *K. opima* and *M. meretrix*, respectively, based on 50% survival arrived at by laboratory experiments would therefore, indicate that no clam would ever survive during the rainy season when the average salinity at the sea beds is much lower than the lethal limits. Since no mass mortality of clams has been observed in these beds, it would be logical to assume that the clams get acclimated

TABLE III

PERCENTAGE MORTALITY OF *K. opima* IN VARIOUS CONCENTRATIONS

No. of days	Percentage of sea water 0%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.	—	—	—	—	—	—	—	—	—	—	—	—
2.	—	—	—	—	—	—	—	—	—	—	—	—
3.	—	—	—	—	—	—	—	—	—	—	—	—
4.	10	—	—	—	—	—	—	—	—	—	—	—
5.	30	25	20	10	—	—	—	—	—	—	—	—
6.	20	50	40	25	5	—	—	—	—	—	—	—
7.	15	20	25	15	5	—	—	—	—	—	—	—
8.	25	5	15	10	10	5	—	—	—	—	—	—
9.	10	—	—	5	15	5	—	—	—	—	—	—
10.	—	—	—	5	5	10	—	—	—	—	—	—
	100%	100%	100%	70%	40%	20%	0%	0%	0%	0%	0%	0%

to lower salinity in the gradual phase of dilution, caused by rain water during monsoon.

In order to study the effects of acclimatization to lower salinity on the survival value in clams, similar salinity tolerance experiments were conducted in the months of July and August. The sea water used in these experiments was of salinity 25·0‰ and this was taken as 100 per cent sea water. The results of these experiments are given in Tables III and IV and also represented in figures 3 and 4.

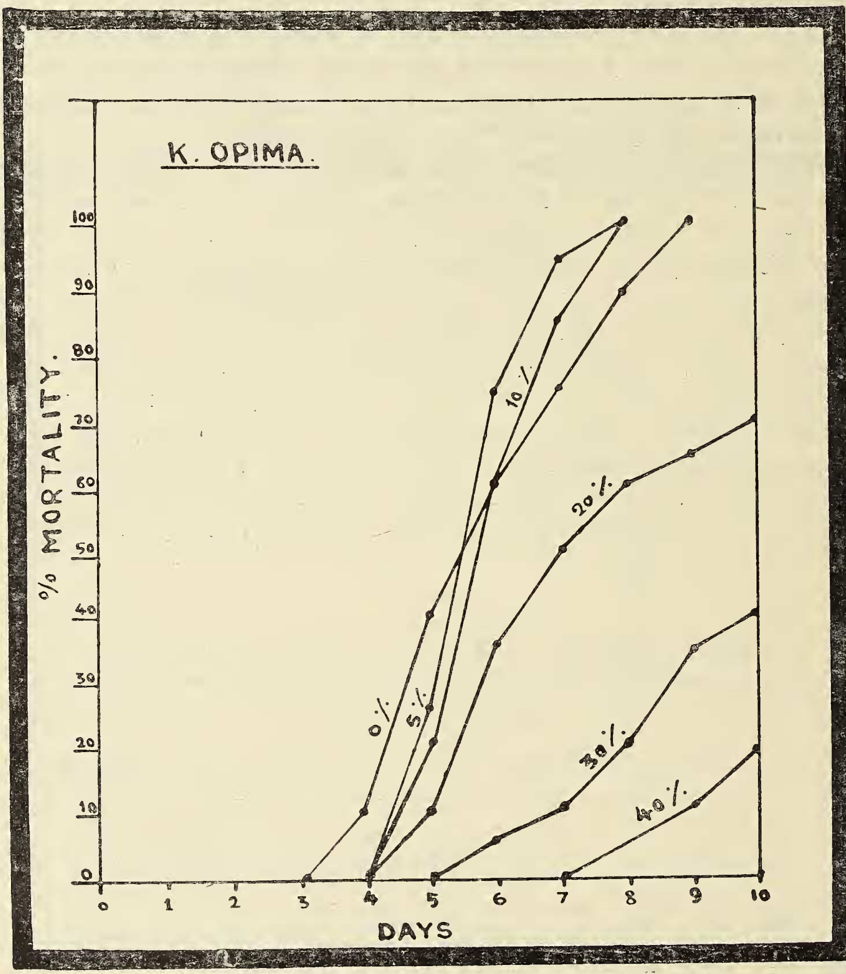

FIG. 3.

From Table III it could be seen that the lower lethal limit for *K. opima* works out to be 30% sea water or 7·5‰ based on 50% survival. This is much lower than the lethal limit found in the previous

TABLE IV

PERCENTAGE MORTALITY OF *M. meretrix* IN VARIOUS CONCENTRATIONS

No. of days	0%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.	—	—	—	—	—	—	—	—	—	—	—	—
2.	—	—	—	—	—	—	—	—	—	—	—	—
3.	—	—	—	—	—	—	—	—	—	—	—	—
4.	—	—	—	—	—	—	—	—	—	—	—	—
5.	10	—	—	—	—	—	—	—	—	—	—	—
6.	30	20	10	—	—	—	—	—	—	—	—	—
7.	10	20	20	5	—	—	—	—	—	—	—	—
8.	30	35	15	10	—	—	—	—	—	—	—	—
9.	10	10	10	5	10	—	—	—	—	—	—	—
10.	10	15	25	10	5	—	—	—	—	—	—	—
	100%	100%	80%	30%	15%	0%	0%	0%	0%	0%	0%	0%

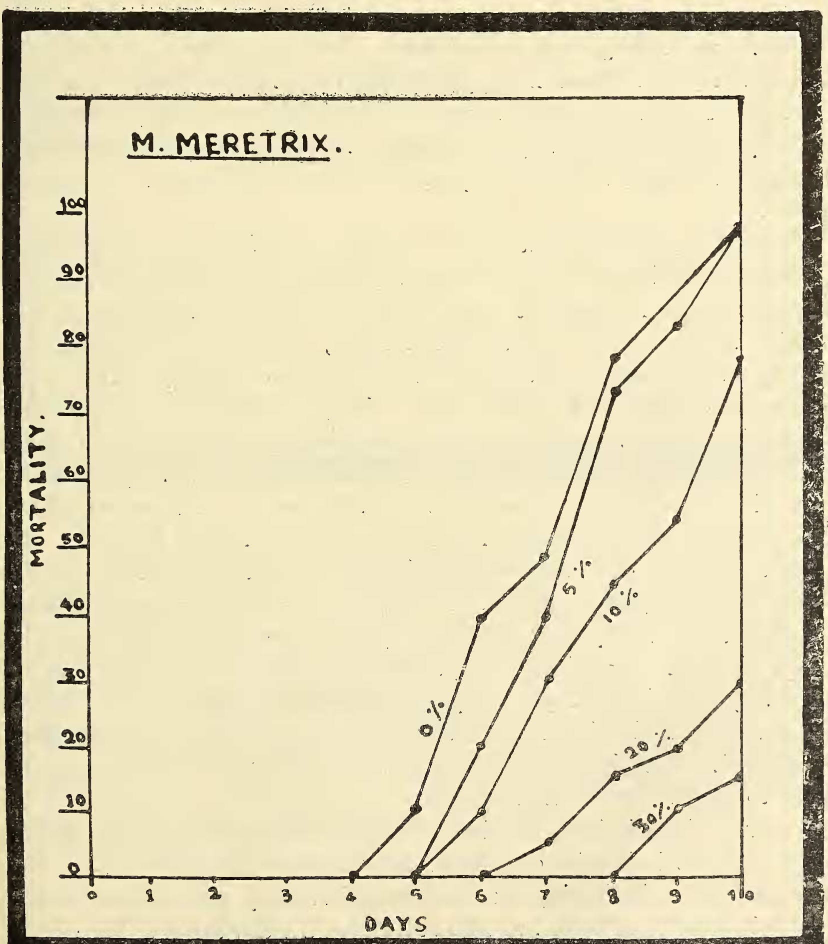

FIG. 4.

experiment viz. 14·0%. Similarly in case of *M. meretrix* (Table IV) the lower lethal limit is reduced to a level of 20% sea water or 5·0‰ as against 10·5‰. This indicates that the continual submergence during the monsoon enables clams to re-act by acclimatization to low salinities and the lethal limits are further reduced to such a level as not to have any harmful effect on the animal. Acclimatization probably helps the clams survive the drastic conditions met with during rainy season.

(2) *Time taken in opening of the valves in relation to salinity :*

While studying the salinity tolerance, it was observed that the clams did not open their valves in low salinities whereas they did so immediately in higher salinities. The relation between the time taken in opening of the valves and the salinity of the external medium was therefore studied in detail. About ten specimens were used in each of the various grades of sea water dilutions and the time taken for opening of the valves was noted.

While conducting these experiments, it was observed that there was some individual variation in the behaviour of clams in different salinities. Some clams took as much as five minutes to open in 100% sea water and only one minute in 70% sea water. Apart from such deviations in certain individuals, the general pattern of behaviour was more or less similar.

For comparison, the mean values of the time taken by ten individuals in different dilutions of sea water are represented graphically in figure 5. From the graph it could be seen that the curves for *M. meretrix* and *K. opima* show more or less a similar trend, though the time taken for opening of the valves in both the species varied slightly. There is a progressively increasing delay in time taken for the valves to open with increase in dilution. In *M. meretrix*, the time taken to open in 100% to 40% sea water was about three minutes, though there was a progressive delay with reduction in the salinity. In 30% sea water however, about eight minutes were required, more than twice the time taken for the valves to open in 40% sea water and above, indicating that the critical salinity was being approached. In 20% sea water the clams behaved very much differently, opening after 1½ to 2 hours for a short time and then closing the valves indefinitely. Thus clams can be said to tolerate nearly 30% dilution and probably the indefinite closing of the valves in 20% sea water and below indicated that salinity of lethal range had been approached. The closure of valves in such cases would be reaction to adjust to unfavourable environment.

A more or less similar behaviour was observed in the case of *K. opima*, except that the indefinite closing of the valves took place in 30% sea water and below indicating that the critical salinity was reached in the range below 40% sea water, as also seen from the deviation of the curve.

Indefinite closing of the valves took place in 30% (10·5‰) and 20% (7·0‰) sea water in *K. opima* and *M. meretrix*, respectively. Changes

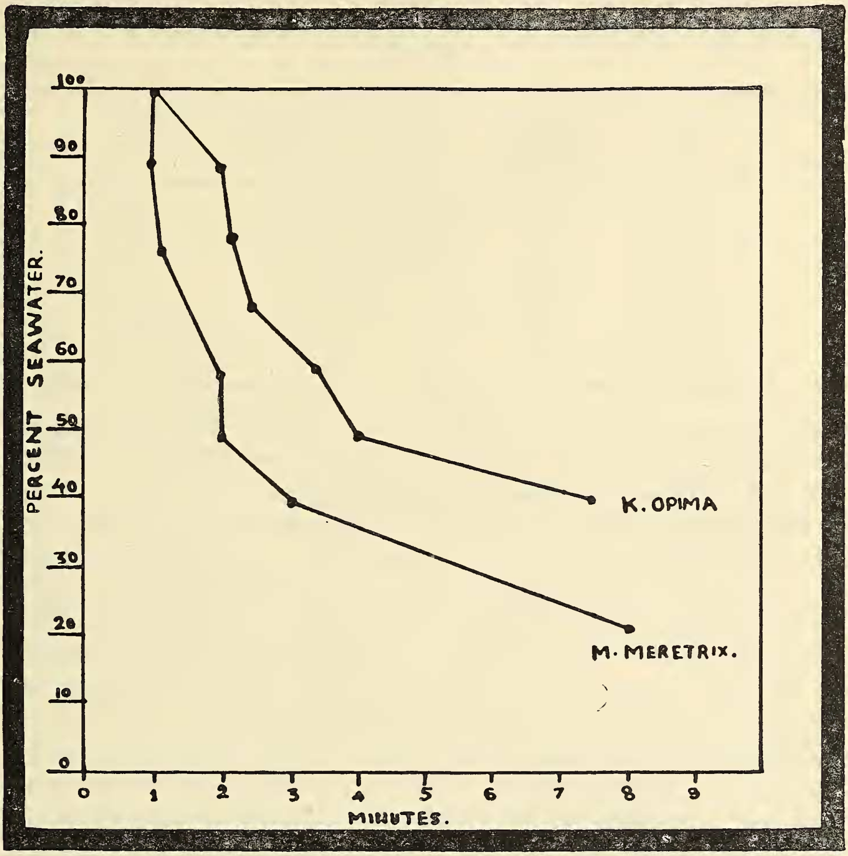

FIG. 5.

in the salinity of sea water during summer and winter are not appreciable but in the rainy season especially in the months of July and August the fluctuations are very great. It was, therefore, considered necessary to study the behaviour of clams in opening and closing of the valves when they are subjected to great fluctuations in salinity as are met with in the rainy season. To determine the changes in the salinity in the monsoon that occur over the clam beds, observations were made for a period of 12 hours on 11th August 1961. The rise and fall in the salinity as observed are given below in Table V.

During the period of 12 hours, the salinity was observed to vary as much as between 1·4‰ to 22·9‰. The lowest salinity was recorded

TABLE V

FLUCTUATIONS IN THE SALINITY OVER THE CLAM BEDS WITHIN A PERIOD OF 12 HOURS (11-8-1961)

Time Hrs.	Salinity Gms/Litre	Tide	Ht. of water Feet	Time Hrs.
06·00	1·4	Low tide	2·9	05·34
08·00	1·4			
10·00	20·4	High tide	13·8	12·22
12·00	22·3			
14·00	22·9			
16·00	8·8	Low tide	5·1	18·30
18·00	8·8			

in the morning at 06.00 hours, when there was a low tide, the height of water being only 2.9 feet. Higher salinities were recorded at 10·00, 12·00 and 14·00 hrs. when there was a high tide with 13·8 feet rise. Then the tide started receding. However, in the evening the low tide (5.1 feet) was not as low as in the morning (2·9 feet) and accordingly, the fall in the salinity was also less (8·8‰). These observations indicate that the rise and fall in the salinity of sea water are very rapid, perhaps because of the tidal effect which is always prevalent in the estuary. The low tide in the morning was at 05·34 hrs. So the incoming tide would start bringing fresh sea water at about 08·30 hrs. The salinity at 08·00 hrs. was still low (1·4‰). Soon after the incoming tide, within a period of 1½ hours the salinity had risen to 20·4‰ indicating a very rapid rise. Similarly with the receding tide the fall in the salinity was also rapid being reduced from 22·9‰ at 14·00 hrs. to 8·8‰ at 16·00 hrs.

In order to find out how the clams react to the drastic changes during rainy season, the following experiment was conducted in which changes in salinities as produced by tidal effects were reproduced in the laboratory. For this purpose an aquarium was set up which was filled with four litres of sea water. To this was added fresh water gradually by means of four inlet flows controlled by clamps. The water in the aquarium tank was continuously aerated in order to effect a thorough mixing. The inlet flows, after sufficient trials, were so adjusted that the salinity of water in the tank would come down to 2·0‰ at the end of six hours. After this the process was reversed. The original quantity of water which was increased by addition of fresh water was again reduced to four litres by siphoning extra water. Then instead of fresh water, sea water was added to the tank in the same way as described above, effecting a gradual rise in the salinity in six hours. Ten clams of each species were subjected to this change and their behaviour was studied. As the experiment was in progress a constant watch was kept on the opening and closing of the valves. As soon as the clams either closed or opened, a sample of water from the tank was drawn and the salinity was determined. The results of the experiment are given in Table VI.

TABLE VI

Time		Salinity gm/lt	Behaviour of clams *M. meretrix*	*K. opima*
		Simulating low tide effect		
0 hr.	9 a.m.	19·3	All opened	All opened
1 hr.	10 a.m.	15·2	,,	,,
2 hrs.	11 a.m.	11·5	,,	One closed
3 hrs.	12 noon	9·4	One closed	All closed
4 hrs.	1 p.m.	6·9	All closed	,,
5 hrs.	2 p.m.	4·4	,,	,,
6 hrs.	3 p.m.	1·8	,,	,,
		Simulating high tide effect		
0 hr.	3 p.m.	1·8	All closed	All closed
1 hr.	4 p.m.	3·9	,,	,,
2 hrs.	5 p.m.	5·4	,,	,,
3 hrs.	6 p.m.	8·9	Two opened	,,
4 hrs.	7 p.m.	11·4	All opened	One opened
5 hrs.	8 p.m.	14·2	,,	All opened
6 hrs.	9 p.m.	18·9	,,	,,

It could be seen from the table that *K. opima* closed their valves indefinitely when the salinity reached 9·4 ‰ whereas *M. meretrix* closed their valves when the salinity reached 6·9 ‰. Similarly *M. meretrix* were first to open up their valves as the salinity started rising. All opened when the salinity rose to 14·2 ‰. However, the opening of the valves, when the salinity was rising, did not take place at the same strength of sea water as was seen when the salinity was falling. Though the valves were closed in the water of 6·9 ‰ in case of *M. meretrix*, for reopening, water of strength 11·4 ‰ was required. Similarly in *K. opima* the valves were opened in water of strength 14·2 ‰ though the phenomenon of closing of valves took place when the salinity was reduced to 9.4 ‰. The difference between the concentration of sea water required for closing and subsequent opening of the valves in case of *M. meretrix* and *K. opima* is 4·5 ‰ and 4·8 ‰, which is approximately the same. It is difficult to explain why higher concentration is required for opening the valves, than the concentration of sea water in which the clams closed their valves indefinitely. It is likely that when the salinity is reducing, the clams with valves open are already circulating water in the mantle cavity and are, therefore, in direct contact with the outside medium. Whereas when the salinity is increasing, the clams are closed and are not in direct contact with the external medium, except perhaps at the edge of the mantle where the stimulus is probably picked up. It is, therefore, likely that some time lapsed before the stimulus reached across the valves to the animal to open the valves. This ' time lapse ' may account for the increase in concentration of the outside medium under experimental conditions. What happens in natural condition is difficult to assess, but as seen above the rise in the salinity is very rapid with incoming tide and " time lapse " felt under laboratory conditions on account of gradual and even rise throughout the pericd of six hours, is either not felt at all under natural conditions or is greatly minimised owing to very rapid rise in the salinity.

It has been already observed that the effect of acclimatization reduces the lethal salinity to 7·5 ‰ and 5·0 ‰ in case of *K. opima* and *M. meretrix*, respectively. As seen above the closing of the valve takes place in 9·4 ‰ and 6·9 ‰ respectively, in both the species. Therefore, in closing the valves indefinitely at a salinity slightly above the lethal salinity, the animals isolate themselves from the unfavourable environment. Thus, in the mechanism of closing the valves, the clams have found an ideal way to survive unfavourable conditions.

(3) *Efficiency of the valve closing mechanism :*

It has been shown above that in lethal salinities the animals close their valves to isolate themselves from unfavourable environment. But in intermediate salinities the time taken for the valves to open varies with the salinity. It was, therefore, natural to assume that some sort of stimulus must reach the animal, while still closed, by which it then regulates the opening of the valves, opening being delayed as the dilution increases. This stimulus is either reached across the animal on account of slight leakage when the shell valves are apparently closed, or it acts directly on the edge of the mantle.

In order to find out if any exchange of water took place between the mantle water and that of the outside medium when the valves are apparently closed, the following experiment was conducted. The clams from natural sea water were subjected to low salinity (20 ‰) in which both the species do not open their valves for a long time, and samples of mantle water were taken every hour for three hours to see how much dilution had taken place. Two sets of experiments were conducted with each species and the mean values obtained are given in Table VII below :

TABLE VII

Species	Salinity of the mantle water	Salinity of the outside medium	Changes in the salinity of the mantle water owing to immersion in low salinity after......		
	(salinity gm/1t)		1 hr.	2 hrs. (salinity gm/lt)	3 hrs.
K. opima	33·0	7·0	0·40	2·20	3·20
M. meretrix	33·0	7·0	0·40	2·60	3·80

From Table VII, it will be seen that the change in the salinity of the mantle water was only 0·40‰ at the end of the first hour in both the species whereas at the end of the third hour the change was 3·20‰ and 3·80‰, i.e. about 9% and 10% in case of *K. opima* and *M. meretrix*, respectively. Thus it can be said that when the shell valves are closed they provide quite an adequate protection to ward off the unfavourable environment, especially of low salinity against diffusion of water. However, it also follows, on the other hand, that clams are unable to ensure complete closure in nature and prolonged immersion in low salinities would be detrimental.

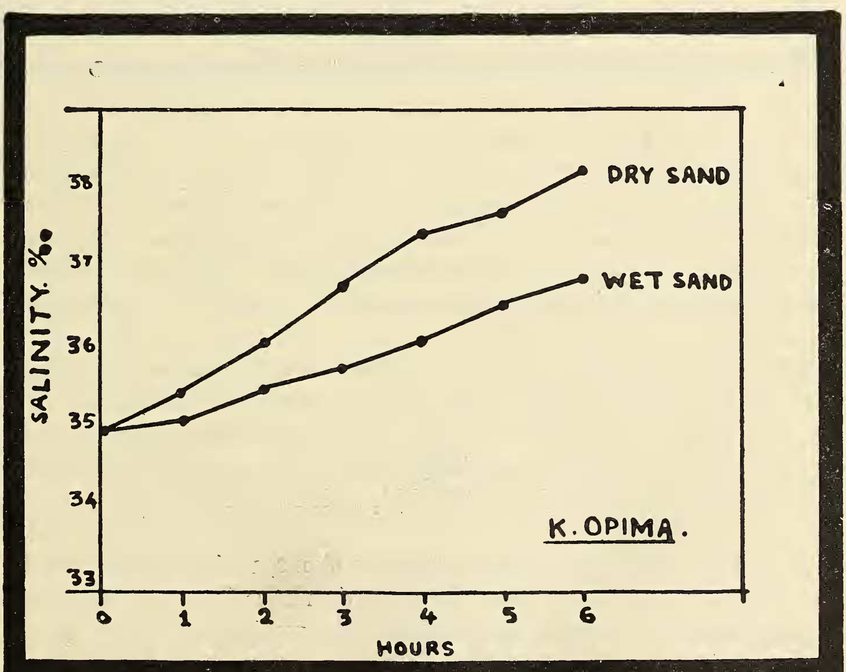

FIG. 6.

When the tide goes out and the clam beds are completely exposed to air the clams in their natural habitat are subjected to desiccation, one more handicap besides low salinities. To study whether there is loss of water from the mantle cavity when the clams are exposed to air, the following experiment was conducted. Two enamel trays were taken and in one a 2 in. thick layer of sand from the Kalbadevi estuary was filled and wetted with sea water, and in the other only dry sand was kept. The idea was to simulate in the first tray a natural condition when the tide runs out, and in the second a rather drastic condition for comparison. Changes in the salinity of the mantle water were determined every hour for a period of six hours. The results of the experiment are given in Table VIII and are represented graphically in figures 6 and 7.

TABLE VIII

	K. opima		*M. meretrix*	
*Hours	Wet sand	Dry sand	Wet sand	Dry sand
1.	35·09	35·54	35·15	35·60
2.	35·54	36·14	35·54	36·20
3.	35·79	36·83	35·79	36·75
4.	36·14	37·53	36·48	37·74
5.	36·48	37·75	36·75	37·80
6.	36·83	38·22	37·54	38·90

* The clams were conditioned in sea water of salinity 35.0 ‰.

From the graphs and Table VIII, it could be seen that there was very little change when both the species were exposed to air, the change being slightly less in *K. opima* than in *M. meretrix*. In wet sand the change in the salinity of the mantle water was 1.83 ‰ in *K. opima* and 2·54 ‰ in *M. meretrix* at the end of six hours, giving an average rate of evaporation of 0·35 ‰ and 0·42 ‰ per hour, respectively. However, the actual rate of evaporation for the first hour was 0·09 ‰ and 0·15 ‰ in *K.opima* and *M.meretrix*, respectively.

When exposed to dry sand, the salinity of the mantle water was, on the whole, slightly higher than in those exposed to wet sand. The rate of evaporation in this case was 0·54‰ and 0·65 ‰ per hour in *K.opima* and *M. meretrix* respectively, and the actual rate of evaporation for the first hour was 0·54 ‰ and 0·60 ‰ which was similar to the mean rate of evaporation.

From this, it can be concluded that the clams, under natural conditions of receding tides exposing the beds, do not suffer much from the evaporation of the mantle fluid, and that the mechanism of closing the valves is quite adequate to protect them until such period the tide turns in and covers the beds. From the experiment conducted with dry sand, it may be said that the valve-closing mechanism in these clams is adequate enough to tide over drastic conditions which are rarely met with in the nature.

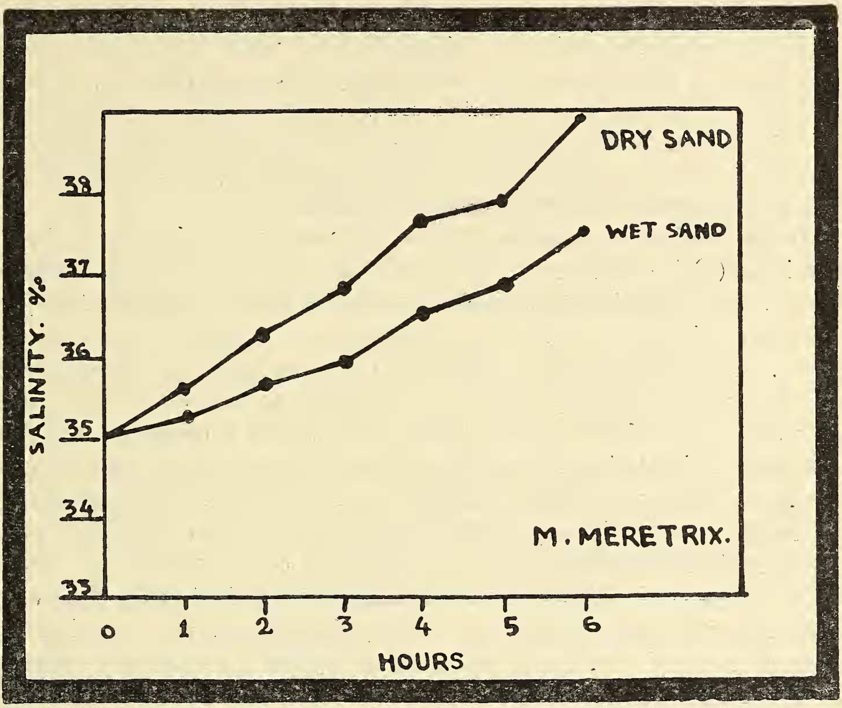

FIG. 7.

(4) *The nature of stimulus which controls the opening and closing of valves :*

In the earlier experiment it was described that the clams when subjected to low salinity (20% sea water and less) do not open their valves. However, when they are transferred back to normal sea water, they open the valves within a few minutes. The question now arises, how does the animal come to know that it is in the right surrounding so as to open the valves for circulating water for breathing and feeding? Since the time taken for the valves to open is progressively delayed with dilution, as shown earlier, it is logical to assume that the sensitivity of the clams to salinity must be due to either change in the ionic concentration of the external medium or the osmotic pressure of the solution to which they are exposed.

Since sodium chloride is the major constituent of sea water, it was considered that either sodium or chloride ions may have effect on the opening of the valves. The experiments conducted are described below :

Taking distilled water as the base, only the sodium ions were raised in the solution to about that of sea water by adding sodium sulphate.

The clams of both the species were subjected to this solution. It was found that the clams did not open up their valves indefinitely in this solution indicating that the sodium ions had no effect on the opening of the valves.

In the second experiment, taking distilled water as the base, only chloride ions were raised by addition of magnesium chloride. Clams subjected to this solution also did not respond and thus it was inferred that chloride ions were also not responsible for causing the stimulus.

Thus it became evident that the ionic concentration of either of the major ions is not responsible for the stimulus.

In the third set of experiments, distilled water was taken as the base, and its osmotic pressure was increased by using a non-electrolite (glycerine). This solution, to be isotonic with sea water, of salinity 34·8‰, was prepared by adding 76·4 cc of glycerine to water to make it up to a litre. When the clams were subjected to this solution, it was observed that they reacted exactly in the same manner as they do so in normal sea water. The clams opened their valves within a couple of minutes and started circulating this solution though there was no trace of any salt in it. This undoubtedly shows that it is the osmotic pressure of the solution which is responsible for the stimulus and not the ionic concentration controlling the initial opening of the valves. It would be interesting to investigate how this stimulus is picked up by the clams when their valves are closed. It is likely that the stimulus is picked up at the external edge of the mantle, perhaps by the contact chemoreceptor cells, but needs thorough investigation.

Discussion

For efficient management of shellfish resources it is necessary to consider several factors, the most important being salinity. The minimum salinity at which the clams can survive and are able to circulate water for feeding must be known and at the same time it is essential to know how long they can survive in unfavourable salinity and what are the factors that affect the length of survival time.

It has been shown above that the two species have different survival values in low salinities. *M. meretrix*, which is more tolerant, survives in as low as 10·5‰, whereas *K. opima* can tolerate only up to 14·0‰ salinity. During monsoon period when saline conditions are lower, the clams get acclimatized to these conditions and become more tolerant to lower salinities. The lethal salinities during this period get reduced to 5·0.‰ and 7·5‰ for *M. meretrix* and *K. opima* respectively. On account of this acclimatization, the clams can survive the salinity dilutions prevalent during the monsoon period. *K. opima* has been observed to survive in pure fresh water for about 60 hours and *M. meretrix* for about 120 hours, both on the basis of 50% survival. This survival period is enhanced during monsoon on account of acclimatization to low salinity. *K. opima* and *M. meretrix* can survive for about 120 and 168 hours respectively. Considering the habitat where these clams are found, this period of survival in fresh water is enough to tide over the unfavourable conditions met with in monsoon. On account of the more tolerant nature, *M. meretrix* has succeeded in penetrating the estuary, whereas *K. opima* is more marine.

The time intervals in opening valves in clams is progressively more as the salinity reduces, and beyond the critical salinity the valves are closed indefinitely so as to withstand the unfavourable environment. In this behaviour also salinity plays an important part in opening and closing of the valves.

There is evidence that the growth in these clams is considerably retarded during the monsoon period. It is, therefore, natural to assume that on account of low salinity during monsoon, the clams are apt to keep their valves closed for longer periods in order to protect themselves from the lethal low salinity, resulting in an inability to circulate water for feeding purpose. However, the process of acclimatization prevents complete cessation of feeding activity during monsoon and the clams are able to feed even at a much lower salinity than the lethal low salinity observed during other periods of the year. It is likely, therefore, that during monsoon clams feed at the high tide only when the salinity is slightly raised on account of influx of sea water, indicating reduction in the intensity of feeding. This may, perhaps, account for the retardation of growth in clams during monsoon.

The valve closing mechanism in the two species of clams has been shown to be an adequate adaptation despite the slight leakage. The desiccation experiments also indicated the same adaptation. Owing to this, clam fishery is supported in an estuary, where the salinity fluctuations are great and where also the animals are at times exposed to air when the tide runs out.

It has been shown above that the clams are sensitive to environmental changes even when apparently closed. There are three possibilities as to how this may happen when the clams are apparently closed.

1. The animals may react to changes in concentration of the mantle fluid which may result through the slight leakage when the valves are apparently closed.

2. The edge of the mantle may act as a semipermeable membrane resulting in osmotic movements of water across it causing an increase or decrease in the hydrostatic pressure in the mantle cavity.

3. The external edge of the mantle which is the only portion likely

to be exposed, may be sensitive to the changes in the salinity or osmotic pressure of the outside medium.

Experiments conducted on clams show that no appreciable change in the salinity of the mantle fluid takes place, at least for quite some time, when the animals are subjected to low salinity. The changes in the concentration of the mantle water, even after one hour, was 0.4‰, which is negligible. This rules out the first possibility. Since no appreciable change in the mantle water takes place and since only a minute area of the mantle edge is likely to be exposed to the external environment, the second possibility is ruled out. Experiments conducted to study the effect of changes in the major ionic concentrations such as sodium or chloride have clearly demonstrated that either of the ions had no effect. However, experiments with non-electrolyte showed that the inhibitory stimulus in clams resulted from a change in the osmotic pressure and though there was no trace of salt in the experimental solution, the clams opened up and started circulating the solution. Similar observations have been made by Motwani (1956) in case of *Mytilus edulis* from English coast.

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